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DESIGN CONSIDERATIONS FOR MONOLITHIC BEAM FORMERS BASED ON ELECTRO-OPTIC POLYMER PHASE MODULATORS AND STRAIN-INDUCED OPTICAL WAVEGUIDES - POSTPRINT

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14. ABSTRACT
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Design Considerations for Monolithic Beam Formers Based on Electro-Optic Polymer Phase Modulators and Strain-Induced Optical Waveguides

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ABSTRACT

The fabrication and characterization of a 1×4-element integrated beam former based on electro-optic (EO) polymer phase modulators (PM) is summarized including findings related to waveguide loss, near-, and far-field diffraction patterns. Based on this device, two alternate designs are proposed to improve performance: an unequally spaced 1×4-element and an equally spaced 1×8-element beam former both based on EO polymer PMs. Models of these alternative designs indicate that waveguide propagation loss and strong grating lobes, both of which degraded the performance of the initial device, can be substantially improved. The proposed approach explored by the 8-element beam former introduces novel components including strain-induced optical waveguides, hybrid integration of active and passive polymers, modified waveguide diffraction aperture, and directional coupler thermo-optic (TO) switches.

Keywords: Electro-optic polymers, Waveguide modulators, Polymer waveguides, Integrated optics devices, Phased-array imaging systems

1. INTRODUCTION

In recent years there has been considerable interest in designing and developing electro-optic (EO) polymer-based optical phased array antennas [1]. EO polymers are potential material candidates for photonic integrated circuits due to low drive voltage, low cost, and easy to fabricate. However, some difficulties impede the EO polymer beamforming technology to high performance and practical application. For example, the optical insertion loss of a cm-size EO polymer beam former has been an issue to be addressed and the optical coupling problem between closely spaced diffraction elements in polymer optical integrated circuits has to be avoided. In this work we rely on a highly nonlinear EO polymer material to fabricate the phase modulator section of the beam former, and a low loss passive polymer material is considered in an effort to address these issues. We report the design, fabrication, simulation, and basic characterization of EO polymer beam formers. In addition, in order to achieve improved beam directivity and large steering angles we propose an equally spaced 1x8-element EO PM beam former based on a practical combination of technologies including strain-induced optical waveguides [2], hybrid integration [3], a selectively etched diffraction array, and a TO switch.

2. SIMULATION, RESULTS, AND PROPOSED DESIGN

Figure 1 shows a schematic cross section of the optical phase modulator, an overview of the entire device, and a detailed overview of the 1×4-element diffraction array all of which have a ridge structure which enables single-mode operation. The interaction length of our phase modulator was designed to be 1.7 cm. The modulators were made using APC/CLD1, a second-order nonlinear optic guest-host polymer, which consisted of a phenyltetraene bridged high $\mu\beta$ nonlinear chromophore guest and an amorphous polycarbonate host [4], [5]. The optical propagation loss was estimated as 1.7~2.0 dB/cm by using the APC/CLD1 waveguide cutback method while the $V\pi L$ product of the EO polymer (measured using a reference push-pull intensity modulator) was ~4.2 Vcm at 1550 nm [4], [5]. Figure 1(c) shows the output aperture, which has more stringent placement requirements than in the rest of the device. In this section, the waveguides should be placed as closely together as possible (ideally $\leq\lambda/2$) provided the optical coupling between neighboring waveguides is suppressed. Such a compact structure will in turn result in a device with a highly directional diffraction pattern able to

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scan large angles. Our simulations indicate that the minimum waveguide-to-waveguide spacing without suffering a crosstalk penalty is 16 μm; a separation much larger than the operating wavelength which significantly limits the performance of this device.

Given our spatial constraints it comes as no surprise that strong grating lobes were predicted by simulations [see Fig. 2(a)-(c)] and experimentally confirmed in Fig. 2(d)-(f) [1]. Grating lobes, which drain power from the main lobe and create spatial ambiguities, have a deleterious influence on the phased-array performance and should be eliminated to the extent possible [6]. To optimize the beam-former design, good beam directivity and steerability are the two most important figures of merit targeted in this work. These improvements can be accomplished by minimizing the width of the main lobe, eliminating grating lobes, and suppressing side-lobe amplitudes. In this work, we investigate two diffraction array architectures: an unequally spaced 1×4-element phased array and an equally spaced 1x8-element phased array both designs are shown in Fig. 3. The intensity of the grating lobes in Fig. 3(a), (b) has been significantly reduced compared to the findings in Fig. 2(a)-(c) through the aperiodic element placement. By increasing the number of elements while reducing their separation from one another, Fig. 3(c)-(e) also demonstrates that the grating lobes will be substantially reduced. On the other hand, optical propagation loss remains a serious issue that must be addressed in all future work. The total length of the device shown in Fig. 1(b) was only 43 mm but still resulted in insertion loss of ~35 dB. The optical propagation loss in the hybrid passive-active polymer could be minimized by using stain-induced optical waveguides which use an etchless fabrication technique on the polymers as shown in Fig. 4 [2]. The deposition of a metal strip on top of the polymer introduces a strain-induced refractive index change within the core layer thus providing better lateral optical mode confinement and potentially lower losses. In order to reduce the total device loss the proposed design will; 1) replace the active region with a low loss passive polymer except in the area of the phase modulator array, 2) implement a hybrid integration technique with low excess loss, 3) apply the etchless fabrication technique to reduce scattering loss, and 4) install low loss TO coupler switches to control optical routes.

Figure 5 explains the concept of the stain induced optical phase modulator integration in greater detail by highlighting the adiabatic waveguide transition from the passive to the active polymer. The proposed design of a 1×8-element integrated polymer optical phase modulator beam former based on hybrid active-passive integration, strain induced optical waveguides, thermo-optic switches in an optical integrated circuit is shown in Fig. 6. Finally, the advantage of using a passive optical polymer is that it can provide low-loss optical waveguides and its mode can be made to match that of a 4.0~4.5 μm small-core fiber which will reduce coupling loss.

3. CONCLUSION

In conclusion, we presented the design, fabrication, and a proof of principle experiment which demonstrates coherent optical beam forming using a 4-element EO polymer PM array. To eliminate the grating lobes, and suppress the side lobes [5] an unequally spaced 4-element and an equally spaced 8-element EO PM beam former diffraction array have been proposed. The proposed devices will be constructed using the following individual technologies: 1) passive optical waveguide technology to provide low-loss propagation and low optical coupling losses, 2) a vertical polymer etching technique designed to adiabatically couple light to a higher index upper core layer and then back down, 3) the stain-induced optical waveguide technique to reduce optical propagation loss, 4) the TO switch in closely spaced parallel single-mode waveguides, and 5) grating-lobe suppression achieved by reducing the waveguide spacing of the diffraction array. Although this final approach mentioned above would normally lead to a detrimental optical coupling between the neighboring waveguides, the coupling can be suppressed by using a selective etch technique to form a grove between the diffraction elements as shown in Fig. 6 thereby more strongly localizing the mode and minimizing coupling between neighboring waveguides.

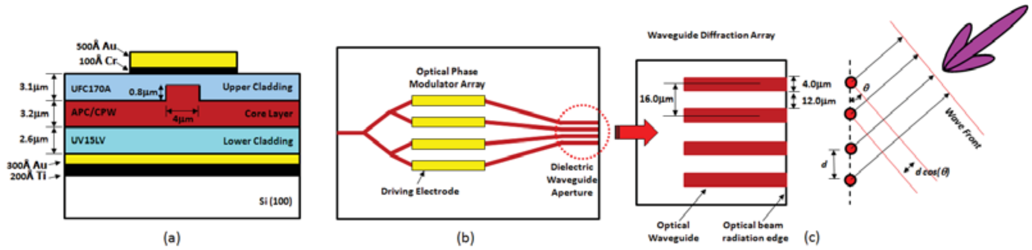

Fig. 1. A schematic design of the electro-optic polymer phase modulator (a), an overview of the overall device layout (b), and the 1x4-element output aperture of the phased array.

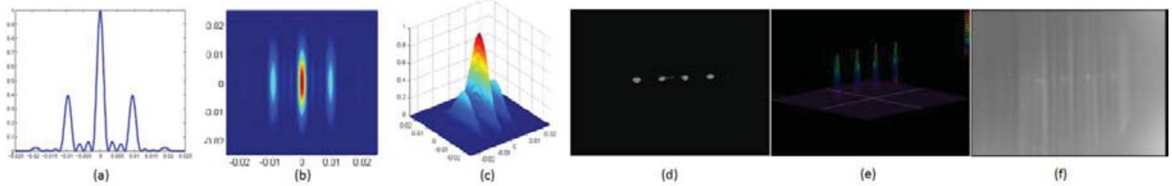

Fig. 2. The predicted intensity cross-section (a) and its corresponding 2D (b) and 3D (c) distributions for the far-field pattern radiated from our 4-element phased array. Experimentally obtained near-field patterns using an IR-camera (d) and an optical beam profiler (e). The measured far-field diffraction pattern is shown in (f).

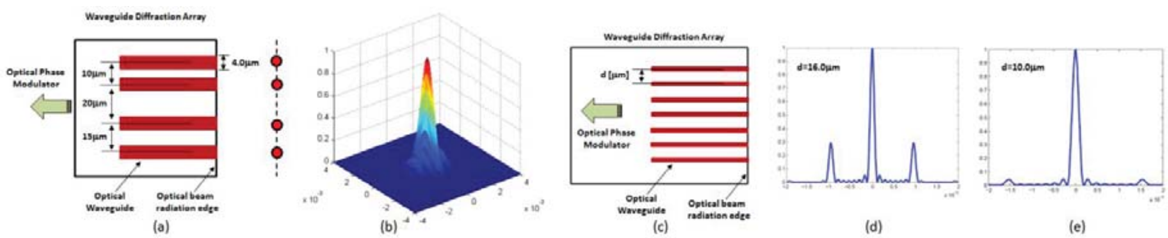

Fig. 3. Proposed design of an unequally spaced 4-element array (a)-(b) and an equally spaced 8 element diffraction array (c)-(e).

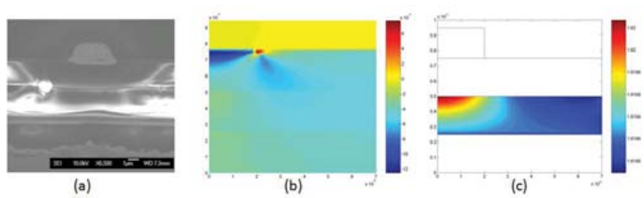

Fig. 4. A preliminary results. (a) a metal strain source, (b) its strain profile, and (c) resulted the refractive index change in core layer.

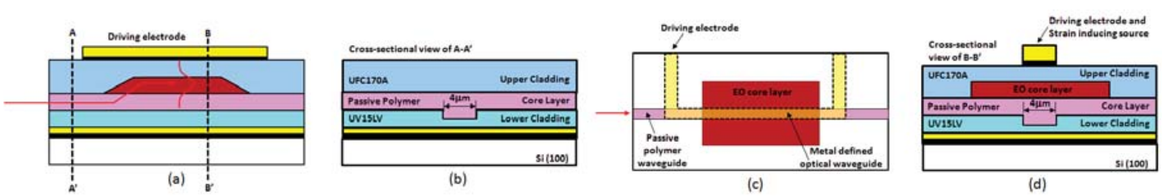

Fig. 5. Proposed hybrid integration technique of the passive-active polymer waveguide and phase modulator in an optical integrated circuit. (a) the optical power traveling in the passive optical waveguide is adiabatically transferred to the higher index active EO polymer and then back down again [3], (b) the passive optical waveguide uses an inverted rib-waveguide structure, (c) a schematic top view of passive rib waveguide, active stain induced optical waveguides, and driving electrode, and (d) cross-sectional view of the active EO polymer phase modulator.

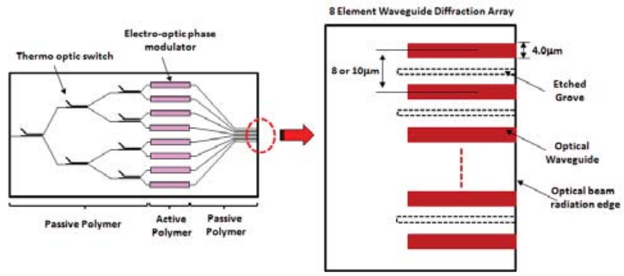

Fig. 6. Proposed design of the 1x8 phase modulator array beam former (left) and the detailed diffraction array description (right)

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